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Thermo field emission in high current arc discharge

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The effect of ion electrical current on the electron thermo field emission from metal surface of cathode in high current arc has been investigated. An electron emission process are considered as follow. One electron emitted due to field of ions in cathode layer is captured by ion to form an exited neutral atom which is then ionized by the electrical field. It is shown that in high current arc random fluctuation of electrical field induced by ions contributes significantly to this kind of emission. The electron emission coefficient is calculated for a variety of arc parameters and surface conditions. The mechanism of electron emission in arc discharge are discussed.

1.Introduction

One of a basic problem high current arc discharge is a problem of electron emission from metal cathode surface. Extremely high density of current at cathode surface, which exceed 10^7 A/cm^2 and more at rather low voltage of discharge burning, testifies that a mechanism of generation of electrons at the cathode of high current arcs differs from known mechanisms such as field emission or electron-ion emission [1] and is more effective, than in glow discharges. Estimations show, that a current of thermo emission with Schottky correction, arising due to a field of spatial charge of the cathode layer, is not enough for achievement of that current density. The electric field that is necessary for effective emission should be at least on the order more. In [2] a current of electron emission in view of random fluctuation of electric field has been calculated. In [3-7] influence of a field of ions was considered in more detail within the framework of mechanism emission which results from tunnel transition electron from a surface of the cathode in field of the ion falling on the cathode, with the subsequent ionization the formed exited atom by an electric field. However in the calculations of ionization of exited atoms average value of electric field has been used. It does not allow to take into account influence of parameters of a layer of spatial charge and underestimates the calculated emission coefficient. A task of the given work is research of influence of parameters a cathode layer of an electric arc on mechanism electron emission and fluctuations of electric field induced by ions.

2. The simulation model

Let's consider the cathode layer of an electrical arc with density of ions n_i. The electric field $\boldsymbol{E}$ near surface equals to the sum of a fields of ions $\boldsymbol{E}_i$

$$\boldsymbol{E}_i = \frac{Ze}{r_i^3}\boldsymbol{r}_i$$

where $\boldsymbol{r}_i$- distance from a point under observation to an ion, Ze is an ion charge. As the position of ions are random values the field of spatial charge also will have an accidental value. The electric field is characterized by function of distribution of field which is density of probability $W(E)$ presence of field $\boldsymbol{E}$ in a point $\boldsymbol{r}$ and which is determined by the following expression

$$W(\boldsymbol{E}) = \int\dots\int\delta\left(\boldsymbol{E}-\sum_{i=1}^{n}\boldsymbol{E}_i\right)d^3\boldsymbol{r}_1 d^3\boldsymbol{r}_2\dots d^3\boldsymbol{r}_n \quad (1)$$

Integration in (1) has been carried out on all volume of cathode layer V, and $n = Vn_i$, $\boldsymbol{r}_i$ is a random variables with homogeneous density of distribution on volume of spatial charge.

Boundary conditions to (1) were set by introduction of mirror charges relative to surface of the cathode.

The rate of electron emission was determined by emission coefficient γ which was amount of electrons, formed as a result of falling one ion on a surface of the cathode.

$$\gamma = \int_0^\infty W(\boldsymbol{E})\int_\infty^d\int_0^\infty N_{ex}v_i(\boldsymbol{E},\varepsilon)d\varepsilon dx d\boldsymbol{E} \quad (2)$$

where N_{ex} is exited atoms density with exited energy ε, v_i is frequency of ionization of exited atom, d is a distance on which the atom deexitation occurs on the cathode surface.

N_{ex} was determined using continuous equation

$$\frac{d(uN_{ex})}{dx} = \frac{J_{tf}}{e}\sigma - v_i N_{ex} \quad (3)$$

where u is an exited atom velocity which has been chosen to be equal ion velocity because ion-atom exchange process, J_{tf} is a electron thermo field emission current which determined from Richardson-Dushman formula (where electric field strength is equal to the sum of a field of a spatial charge and a field of the

falling ion); σ is a Coulomb electron-ion collisions cross section. Frequency of ionization of exited atoms was determined from [8].

3. Computational results and discussion

The integral (1) was computed by Monte-Carlo method. The computed probability distribution of amplitude of electric field near cathode surface is presented on fig. 1 in dimensionless value for five values of layer thickness l_d. Field is presented in unit $E_0 = 2.603en_i^{2/3}$, layer length is presented in $d_0 = (4\pi n_i/3)^{-1/3}$. All distribution are computed for point located at distance $d_0/2$ from cathode surface.

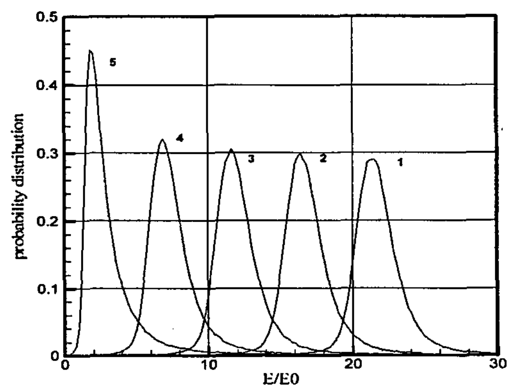

Fig.1 The electric field distribution near cathode surface 1 – l_d = 5, 2 – l_d = 4, 3 – l_d = 3, 4 – l_d = 2, 5 – l_d = 1

One can see that for layer length about (3-5)d_0 and more the probability distribution can be presented as Holtsmark distribution displaced an amount macroscopic field of charge. For small layer the shape of probability distribution changes. The amplitude of probability distribution extend up to value 0.45 and high field part of the distribution rises.

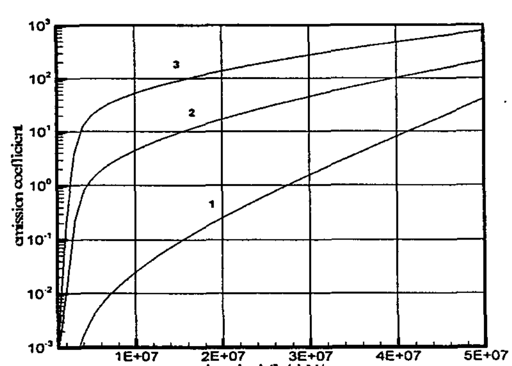

Fig. 2 The emission coefficient dependence on electric field $l_d = 5$; curve 1-T=3000°K, 2 - T=5000°K, 3 -T=7000°K

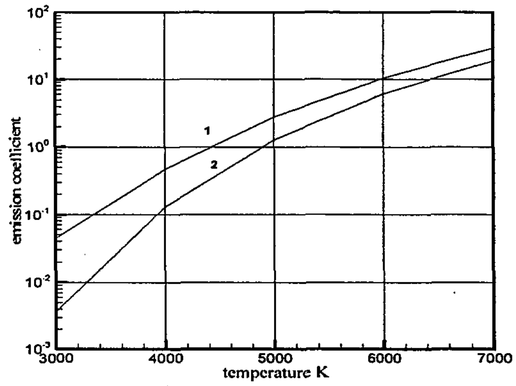

Fig. 3 The emission coefficient dependence on surface temperature E=5·10^6 v/cm with (curve 1) and without(2) field fluctuation; $l_d = 2$.

Fig. 2 and 3 present emission coefficient γ computed from (2) as a function surface temperature and macroscopic electrical field . On figure 3 curve 1 presents calculation γ with field fluctuation, curve 2 presents data computed without considering field fluctuation. One can see the significant difference between both curves.

From Mackeown theory of cathode layer at constant layer voltage drop we see that the thickness of the layer l_d depends on ion current density J_{ion} how $J_{ion}^{-1/6}$. So for big J_{ion} one faces condition where $l_d \leq 1$. ($l_d \approx 1$ at $J_{ion} \approx 10^7 A/cm^2$). It means that random fluctuation of electrical field plays most important role in electron emission at cathode of such electrical arcs.

Acknowledgments

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